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(58) Field of Search
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(54) **Reflecting transponder for calibrating phased-array radar**

(57) A reflector (1) provides delayed reflection of incident microwave radiation, for example in a phased-array radar system. The radar system comprises an array (26) of antenna elements (30) with associated transmitters (32) and receivers (34). The reflector (1) is operative to re-radiate to the antenna elements (30) a relatively delayed equivalent of radiation received at the reflector (1) therefrom. A control unit (42) calibrates the radar system from the relative phase and gain characteristics of the antenna elements (30) and their associated transmitters (32) and receivers (34) determined from the radiation transmitted and received at the antenna elements (30) after re-radiation from the reflector (1). The reflector (1) is enabled/disabled by an optical control signal conveyed to it along an optical fibre (46). The fibre (46) avoids spurious microwave reflections from a region near the reflector (1) which arise if a conductor is employed to convey the control signal. The reflector (1) incorporates an acoustic-wave delay line (8) to delay microwave radiation prior to re-radiation. Both the radar and the reflector may be mounted in the nose of an aircraft.

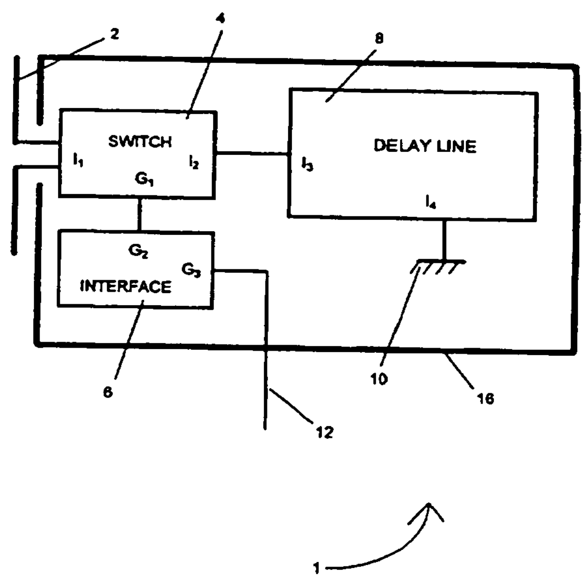

FIGURE 1

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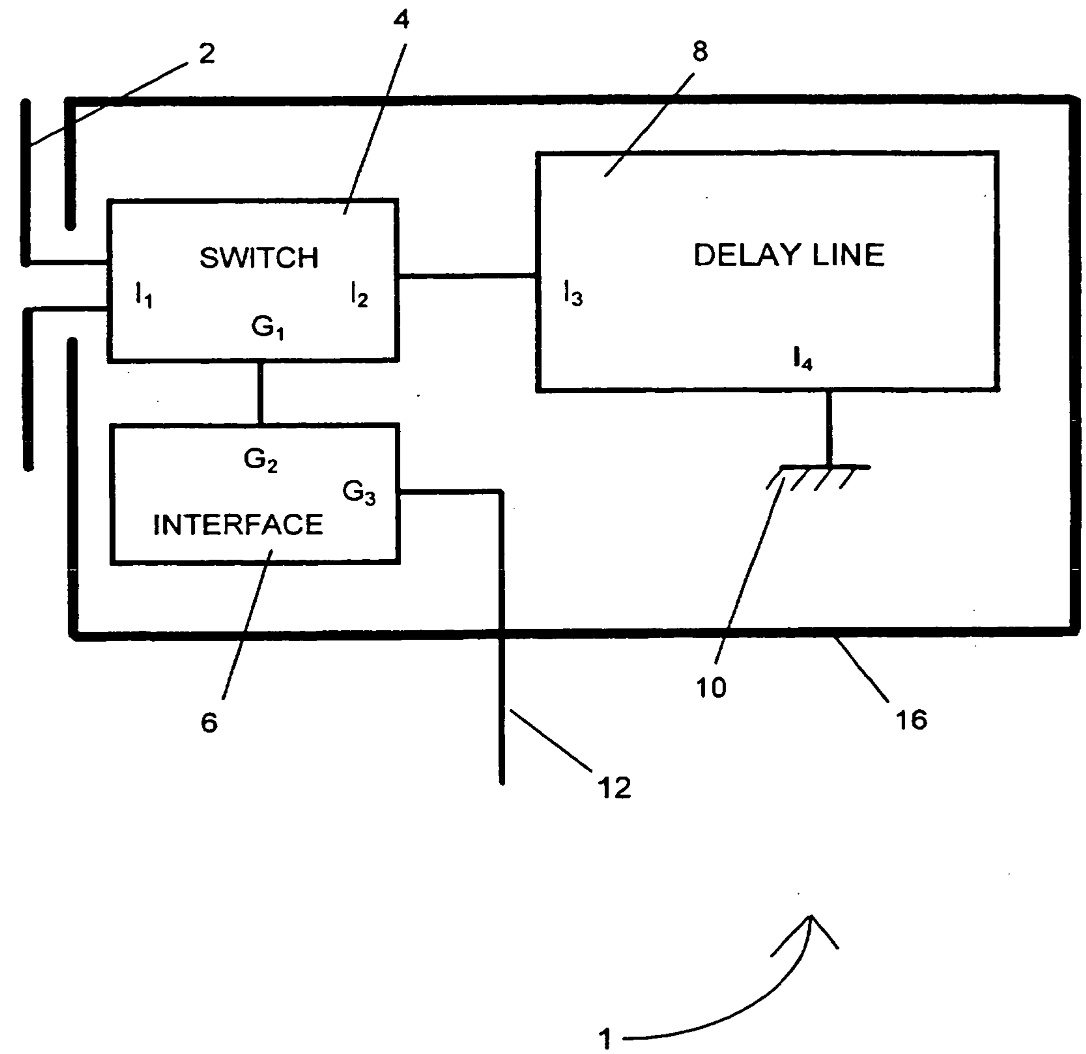


FIGURE 1

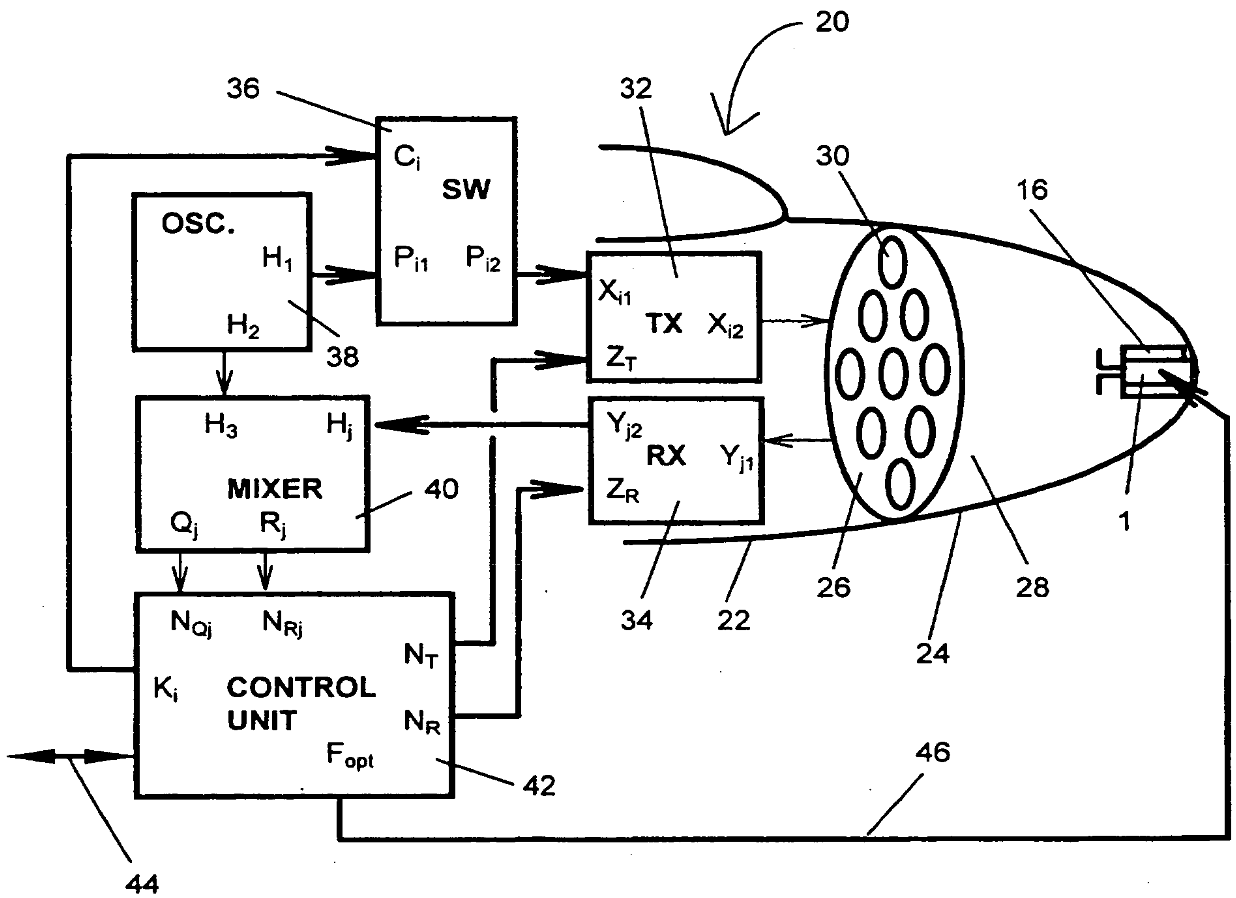
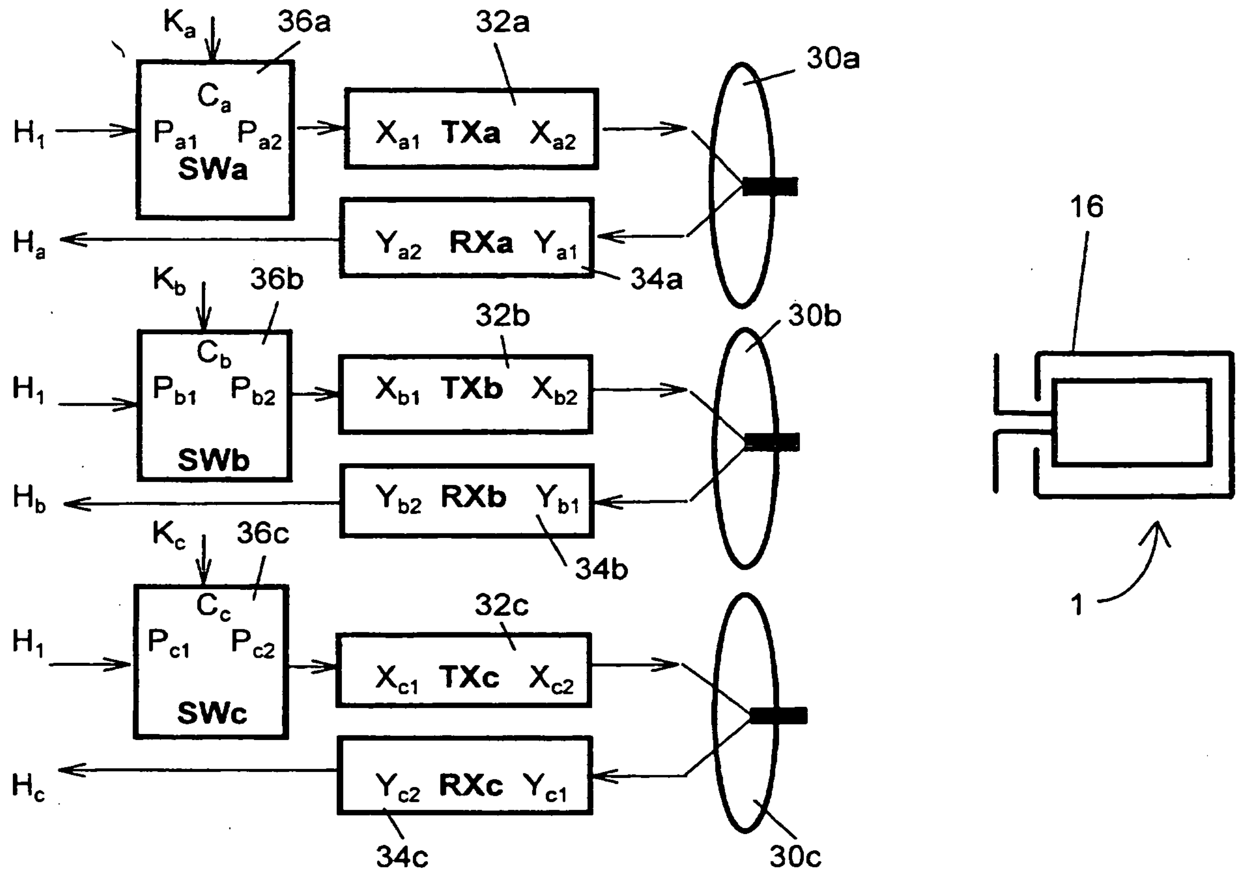

20
36
32
30
16
OSC.
H_1
H_2
38
SW
C_i
P_{i1}
P_{i2}
TX
X_{i1}
X_{i2}
Z_T
RX
Y_{j2}
Y_{j1}
Z_R
MIXER
H_3
H_j
Q_j
R_j
40
CONTROL UNIT
N_{Qj}
N_{Rj}
N_T
N_R
K_i
F_{opt}
42
34
22
26
24
28
1
46
44

FIGURE 2



K_a
36a
32a
30a
C_a
H_1
P_a1
P_a2
X_a1 TXa X_a2
SWa
16
H_a
Y_a2 RXa Y_a1
34a
K_b
36b
32b
30b
C_b
H_1
P_b1
P_b2
X_b1 TXb X_b2
SWb
H_b
Y_b2 RXb Y_b1
34b
K_c
36c
C_c
32c
1
H_1
P_c1
P_c2
X_c1 TXc X_c2
SWc
H_c
Y_c2 RXc Y_c1
34c
30c

FIGURE 3

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REFLECTOR

This invention relates to a reflector, for use in pulse-echo target location systems such as radar systems.

The present invention provides a reflector arranged to receive radiation and to re-radiate a relatively delayed return signal in response thereto.

The reflector provides the advantage that it may be located in close proximity to an associated radar system for reflecting radiation whilst simulating a remote reflector for the radar system. The reflector may be enabled or disabled by using an optical control signal. An optical fibre may be used for conveying the optical control signal.

The reflector incorporates radiation reception and transmitting means, and signal delaying means. The signal delaying means may be an acoustic-wave delay line, and the receiving and transmitting means may be a dipole antenna.

The reflector of the invention is particularly suitable for incorporation into a pulse-echo target location system, for example a radar, sonar or lidar system of the kind incorporating a phased array of emitters and receivers.

In a preferred embodiment, the reflector of the invention is employed in connection with calibration of a radar system to achieve accuracy of radar interrogating beam formation and accuracy of distance measurement. The latter is based upon time taken for a burst of radiation emitted from the radar system to impinge upon an object, be reflected therefrom, and return to the radar system.

Performance verification of a radar system is undertaken by interrogating an isolated object situated at a known distance and direction. The radar system antenna may be steered slightly away from the isolated object in order to measure the polar distribution of the radar beam. In the case of airborne radar systems, a remote isolated object of accurately known relative position may not be available for use in

checking the performance of the radar system whilst in flight. In a preferred embodiment, the reflector of the invention is employed to simulate such an object.

Use of a reflector of the invention makes it possible to calibrate a phased-array radar system. The amplitude and phase of radiation emitted from each element of the system antenna array is controlled with the aid of the reflector in order to ensure satisfactory formation of its radar beam. These amplitude and phase parameters vary with array ageing, with temperature, or with the failure of associated electronic transceiver equipment. Moreover, it is desirable to control receiving gain and phase characteristics of the array elements and their associated electronic transceiver equipment accurately when radiation is incident at the array in order to obtain a high-gain directional receiving response. It is therefore desirable to recalibrate a phased-array radar system at regular intervals so that any deviations in gain and phase characteristics of the array may be corrected. For aircraft-borne microwave phased-array radar systems, it would be particularly advantageous to have the capability of re-calibrating the array whilst in flight. The reflector of the invention makes it possible to achieve this.

The reflector may be incorporated together with calibrating means into a radar system. The reflector is operative to re-radiate a relatively delayed return signal in response to radiation received at the reflector from the radar system, and the calibrating means is operative to determine radar system characteristics in response to the reflector return signal.

This provides means for calibrating the radar system in-situ, for example in-flight in the case of air-borne phased-antenna array systems.

The reflector provides for simulation of an object at a known distance and direction relative to the radar system. It thereby allows actual phase and gain parameters associated with the radar system to be measured and compared with desired values of these parameters; deviations between measured and desired gain and phase parameters may then be used to correct responses of the radar system.

Deviations of measured gain and phase parameters from desired values of these parameters, calculated within the calibrating means, may be used to trim the responses of transceiver equipment in the radar system, or may alternatively be subtracted from phase and gain control signals applied to the transceiver equipment, in order to improve the accuracy of the radar system.

In order that the invention might be more fully understood, an embodiment of the invention will now be described, with reference to the accompanying drawings, in which:

Figure 1 is a schematic drawing of a reflector;

Figure 2 is a schematic drawing of a phased-array radar system and a reflector incorporated into an aircraft; and

Figure 3 is a schematic drawing of phased-antenna array elements and a reflector incorporated in the Figure 2 system.

Referring to Figure 1, a reflector is indicated generally by 1. The reflector 1 comprises a dipole antenna 2, a gating switch 4 comprising a field-effect-transistor (FET) or PIN-diode, an interface element 6 comprising a photodiode, an acoustic-wave delay line 8 and a delay-line termination element 10. The delay line 8 is capable of propagating a surface-acoustic-wave (SAW) or bulk-acoustic-wave at microwave frequencies in the order of 11 GHz. The dipole antenna 2 is connected to the gating switch 4 at a terminal I_1. A terminal I_2 on the gating switch 4 is connected to a terminal I_3 on the delay line 8. The termination element 10 is connected to a terminal I_4 on the delay line 8. A terminal G_3 on the interface element 6 is connected via an optical fibre 12 to a control unit (not shown). A terminal G_2 on the interface element 6 is connected to a terminal G_1 on the gating switch 4. A microwave-absorbing cladding layer 16 surrounds the switch 4, the delay line 8, the interface element 6 and the termination element 10 so that only the dipole antenna 2 and the optical fibre 12 are directly exposed to incident microwave radiation.

Referring to Figure 2, a front section of an aircraft is indicated generally by 20. The aircraft 20 has a fuselage section 22. A nose cone 24 is attached to the front of the fuselage section 22. A reflector 1 is located at an apex region of the nose cone 24. The reflector 1 is partially surrounded by its microwave-absorbing cladding layer 16. A microwave phased-antenna array 26 is situated at a rear region 28 of the nose cone 24 furthest from the reflector 1. The phased-antenna array 26 comprises a plurality of individual array elements such as 30. A transceiver comprising transmitters (TX) 32 and receivers (RX) 34 is connected to the phased-antenna array 26. The transmitters 32 each have a signal input terminal X_{i1}, a signal output terminal X_{i2} connecting to an array element, and a phase/gain control input terminal Z_T. The receivers 34 each have a signal input Y_{j1} connecting to an array element, a signal output Y_{j2} and a phase/gain control input Z_R. Each transmitter 32 is connected from its input terminal X_{i1} to an output terminal P_{i2} of a switch element (SW) 36. The switch element 36 also has an input terminal P_{i1} and a switch control input C_i. The input terminal P_{i1} is connected to a high-frequency microwave output terminal H_1 of a microwave oscillator (OSC) 38.

The signal output Y_{j2} of each receiver 34 is connected to a mixing input H_j of a microwave mixer (MIXER) 40. A second mixing input H_3 of the mixer 40 is connected to an output terminal H_2 of the oscillator 38. The mixer 40 has mixing output terminals Q_j and R_j corresponding to quadrature and in-phase mixing of the signal at the input H_j with an oscillator signal at the terminal H_3 respectively. A control unit 42 has an interface bus 44 connecting to other equipment (not shown), a switch control output terminal K_i connecting to the switch control input terminal C_i of each switch element 36, a phase/gain control output terminal N_T connecting to the phase/gain control input terminal Z_T of each of the transmitters 32, a phase/gain control output terminal N_R connecting to the phase/gain control input terminal Z_R of each of the receivers 34, a quadrature signal input terminal N_{Qj} connecting to the mixer output terminal Q_j of the mixer 40, an in-phase signal input terminal N_{Rj} connecting to the mixer output terminal R_j of the mixer 40, and a terminal F_{opt} connecting via an optical fibre 46 to an input terminal G_3 on the reflector 1.

Referring next to Figure 3, three phased-antenna array elements 30a, 30b, 30c are shown connected to their associated transmitters (TX) 32 which in turn are connected to switch elements (SW) 36, and to their receivers (RX) 34. The reflector 1 is located within the transmission/reception field of view of the phased-antenna array elements 30a, 30b, 30c.

The mode of operation of the reflector 1 will now be described with reference to Figure 1. The dipole antenna 2 receives incident microwave radiation and provides a corresponding microwave signal at the terminal I_1 of the switch 4. The optical fibre 12 conveys a control signal to the terminal G_3 of the interface element 6. The interface element 6 conditions the control signal at the terminal G_3 and provides a conditioned control signal at the terminal G_2 and hence at the terminal G_1 of the switch 4. The conditioned control signal instructs the switch 4 either to convey a microwave signal between the terminals I_1 and I_2 or to isolate the terminals I_1 and I_2 so that a microwave signal may not pass between them. In the case where the switch 4 conveys microwave signals, the microwave signal from the dipole 2 at the terminal I_1 passes to the terminal I_3 of the delay line 8. The microwave signal at the terminal I_3 couples into the delay line 8 and propagates therein as an acoustic wave. This acoustic wave couples out of the delay line 8 at the terminal I_4 as a microwave signal. This microwave signal is reflected at the signal ground 10 and is then coupled into the delay line 8 at the terminal I_4 as an acoustic wave. This recoupled acoustic wave propagates along the delay line 8 and is then coupled out of the delay line 8 at terminal I_3 as a microwave signal. This microwave signal then passes through the switch 4 and is subsequently re-radiated from the antenna 2.

Microwave signal propagation delays from the input I_3 to the output I_4 in the range 50 nanoseconds to 20 microseconds, depending upon the construction of the acoustic delay line 8, are attainable. The delay line 8 may be fabricated from lithium niobate, lithium titanate or quartz. Alternatively, it may be fabricated from a silicon substrate onto which a layer of zinc oxide and then a conductive layer comprising interdigitated electrodes have been applied to enable piezo-electric transduction of microwave signals to and from the silicon substrate. With regard to microwave radiation incident upon the dipole 2 compared to corresponding microwave radiation emitted from the

dipole, the insertion loss of the reflector 1 is in the order of 60 dB. The microwave-absorbing cladding layer 16 prevents microwave radiation incident upon the reflector 1 coupling directly into the switch 4, the interface element 6 or the delay line 8 so that substantial incident microwave radiation is only coupled into and out of the reflector 1 through the dipole 2.

The reflector 1 may be incorporated into a radar calibration system for calibrating a phased-array radar system. The mode of operation of the radar calibration system will now be described with reference to Figures 2 and 3. During normal operation of the phased-array radar system, microwave radiation is emitted from the phased-antenna array 26 towards a distant scene (not shown) which subsequently reflects a portion of the microwave radiation back to the phased-antenna array 26 again for reception; the reflector 1 is set in an inactive state which will be explained in more detail later.

During operation of the radar system when it interrogates a remote scene, the control unit 42 communicates through the interface bus 44 with other data processing and display units (not shown) which define a desired direction for radar interrogation. On receiving instructions through the interface bus 44, the control unit 42 sets a desired phase and gain response for each of the transmitters 32, by sending signals from the terminal N_T to the terminal Z_T, and for each of the receivers 34, by sending signals from the terminal N_R to the terminal Z_R, in order to define a radar beam emission direction and radar reception direction. The control unit 42 then sends a gating signal, from its terminal K_i to the terminal C_i on each switch element 36, which gates a continuous microwave signal provided at the terminal H_1 of the oscillator 38, and hence at the terminal P_{i1} of each switch element 36, to provide a burst of microwave signal at the terminal P_{i2} on each switch element 36; the burst of microwave signal at the terminal P_{i2} is conveyed to the terminal X_{i1} on the transmitter 32 from whence it passes, with modified amplitude and phase determined by the signal applied at the terminal Z_T, to the terminal X_{i2} and finally to an array element 30 for emission as microwave radiation. A microwave radar beam formed thereby is incident on a remote scene (not shown) which reflects a portion of the incident radar beam. Some of this portion of reflected radiation is received at the array elements 30 and is

conveyed as a microwave signal to the terminal Y_{j1} of the receiver 34. The microwave signal at the terminal Y_{j1} passes through the receiver 34, in which the amplitude and phase of the signal at the terminal Y_{j1} are modified, to the terminal Y_{j2} and thence to the terminal H_j of the mixer 40 associated with the receiver 34. The microwave signal at the terminal H_j is then mixed with a microwave signal from the terminal H_2 of the oscillator 38, conveyed to the terminal H_3 of the mixer 40, which is phase coherent with the burst of microwave radiation emitted from the array 26; this mixing generates two outputs Q_j and R_j which are in-phase and quadrature components of the signal at the terminal H_j relative to the signal at the terminal H_3. The quadrature signal Q_j and the in-phase signal R_j are conveyed to the terminal N_{Qj} and N_{Rj} of the control unit 42 respectively where they are monitored by the control unit 42. The control unit 42 then processes the signal at the terminals N_{Qj} and N_{Rj} and passes information derived thereby through the interface bus 44 for subsequent processing and display.

During a calibration phase of the phased-array radar system in which the radar system interrogates the reflector 1 instead of a remote scene, an instruction is passed to the control unit 42 via the interface bus 44 that a calibration operation may be undertaken. The control unit 42 outputs a signal from the terminal F_{opt} which is conveyed by the optical fibre 46 to set the reflector 1 in an active state. The reflector 1 has two modes of operation, that is an active mode and a passive mode. In the active mode, it provides a delayed microwave reflection. In the inactive mode, it does not provide any delayed microwave reflection. It is switched between these modes by applying a control signal through the optical fibre 46 to the terminal G_3 on the interface element 6; this control signal at the terminal G_3 in turn controls a signal at the terminal G_2 of the interface element 6 and hence a control signal at the terminal G_1 of the switch element 4 so that microwave signals may either pass in the active state, or may not pass in the inactive state, between the terminals I_1 and I_2 of the switch element 4. As a result, microwave signals are conveyed between the dipole antenna 2 and the delay line 8 when (and only when) the reflector 1 is in the active state. The delay line 8 provides a propagation delay in the range 50 nanoseconds to 20 microseconds (depending upon the design of the delay line 8 installed) for microwave signals at the terminal I_3 to reach the terminal I_4, and a similar delay for

microwave signals at the terminal I_4 to return to the terminal I_3. The delay-line termination element 8 ensures that a microwave signal at the terminal I_3 which propagates to the terminal I_4 is reflected back through the terminal I_4 to the terminal I_3 again. The effect of the delayed microwave reflection from the reflector 1 is to simulate a radar return from a remote target which is at a predetermined constant distance and direction relative to the phased-antenna array 26. Such a simulated target is used by the control unit 42 to characterise the individual phased-antenna array elements and their associated transmitters 32 and receivers 34 and thereby determine their phase and gain characteristics. These determined phase and gain characteristics are then compared in the control unit 42 with desired phase and gain characteristics and any deviations between these determined and desired characteristics are subtracted from the signals N_T and N_R which would be required during operation of the radar system interrogating a remote scene if deviations between the determined phase and gain characteristics and the desired phase and gain characteristics were negligibly small. The terminal G_3 is configured to accept a control signal conveyed by means of the optical fibre 46 so that electrical conductors, which could give rise to spurious reflections, are not contained within the nose cone 24; the interface element 6 comprises a photodiode and operating power is conveyed to the reflector 1 as light (including infra-red) radiation through the optical fibre 46.

During the calibration operation, a gain-phase mapping, given in Equation 1, relates a microwave signal $\mathbf{U}_0$ applied to the terminal X_{i1} to a signal $\mathbf{S}_{ij}$ obtained at the terminal Y_{j2}:

$$\mathbf{G}_{RXj}\,\mathbf{A}_{RXj}\,\mathbf{G}_{Tij}\,\mathbf{A}_{TXi}\,\mathbf{G}_{TXi}\,\mathbf{U}_0 = \mathbf{S}_{ij} \qquad \text{Eq. 1}$$

where

i and j are reference indices in the range 1 to n for which n is the number of array elements 30 in the array 26, a vector operator $\mathbf{G}_{TXi}$ describes a microwave signal transfer function of the transmitter 32 with a reference index i, a vector operator $\mathbf{A}_{TXi}$ describes a microwave signal-radiation transfer function of an array element 30 associated with the transmitter 32 with a reference index i, a vector operator $\mathbf{G}_{Tij}$

describes a microwave signal transfer function of the reflector 1 in an active state for incident radiation from an array element with reference index i to an array element with reference index j, a vector operator $\mathbf{A}_{RXj}$ describes a microwave radiation-signal transfer function of an array element 30 associated with the receiver 34 with a reference index j, and a vector operator $\mathbf{G}_{RXj}$ describes a microwave signal transfer function of the receiver 34 with a reference index j.

The vector operator $\mathbf{G}_{Tij}$ may be assumed to be invariant during the period required for calibrating the radar system when the reflector 1 is set in an active state; the vector operator $\mathbf{G}_{Tij}$ accounts for factors such as the polar response of the reflector 1, the distance between the reflector 1 and a given array element 30, as well as the microwave signal delay and insertion loss provided by the reflector 1. The vector operators $\mathbf{A}_{TXi}$ and $\mathbf{A}_{RXj}$ relating to the array elements 30 account for microwave signal propagation through the array elements 30 themselves as well as microwave radiation polar transmission and reception response of the elements 30. The vector operators $\mathbf{G}_{TXi}$ and $\mathbf{G}_{RXj}$ account for gain and phase responses of the transmitters 32 and receivers 34 respectively. If a given array element i is used to transmit a burst of microwave radiation for calibrating the radar system, $\mathbf{A}_{TXi}$ $\mathbf{G}_{TXi}$, and $\mathbf{U}_0$ are similar for all the received signals $\mathbf{S}_{ij}$; since $\mathbf{G}_{Tij}$ may be precharacterised and hence known, and arranged to be invariant during the calibration, the signal $\mathbf{S}_{ij}$ (with i constant) at each receiver 34 uniquely defines $\mathbf{G}_{RXj}$ $\mathbf{A}_{RXj}$. Vector components of $\mathbf{S}_{ij}$ relative to $\mathbf{U}_0$ are evaluated by measuring the signals at the terminals Q_j and R_j of the mixer 40 for each of the array elements 30. The gain response is calculated in the control unit 42 from the root of the quadratic sum of Q_j and R_j whereas the phase response is calculated from the arctan of a fraction Q_j/R_j. From measurement of the signal $\mathbf{S}_{ij}$ provided at the output Y_{j2} of each receiver 34, a relative phase and gain response for each element 30 and its associated receiver 34 is determined.

Moreover, if a given array element 30 with reference index j together with its associated receiver are used to receive a signal $\mathbf{S}_{ij}$ where each element 30 with associated transmitter 32 transmits a burst of microwave radiation in turn, $\mathbf{G}_{RXj}$ $\mathbf{A}_{RXj}$ is invariant during the calibration hence each measurement of the signal $\mathbf{S}_{ij}$ uniqu ly defines $\mathbf{A}_{TXi}$ $\mathbf{G}_{TXi}$.

In this manner, relative gain and phase responses of the array elements 30 and their associated transmitters 32 and receivers 34 may be calculated in the control unit 42. These relative phase and gain responses are stored as data in the control unit 42 and used for making error corrections to the signals provided at N_T and N_R for subsequent radar beam formation when the radar system is not in the calibration mode of operation, that is interrogating a remote scene.

Referring now to Figure 3 once more, a method of determining the relative phase and gain characteristics of each array element for emission and reception of microwave radiation is as follows with regard to the three array elements 30a, 30b, 30c. Initially, the reflector 1 is set in an active mode so that it provides delayed reflection of incident microwave radiation emitted from the elements 30. A microwave signal $\mathbf{U_0}$ from terminal H_1 on the oscillator 38 is applied to the transmitter TXa and transmitted from the array element 30a which emits the signal as microwave radiation. Part of the radiation is received at the reflector 1, undergoes delay therein, and is returned by retransmission from the reflector 1 to the phased-antenna array 26. The returned microwave radiation is received by the array elements 30a, 30b and 30c and processed by the receivers RXa, RXb and RXc to give received signals $\mathbf{S_{aa}}$, $\mathbf{S_{ab}}$ and $\mathbf{S_{ac}}$ respectively which are mixed to give quadrature and in-phase signal components which are then recorded in the control unit 42.

This procedure is repeated using the transmitters TXb and then TXc to give received signals $\mathbf{S_{ba}}$, $\mathbf{S_{bb}}$, $\mathbf{S_{bc}}$ and $\mathbf{S_{ca}}$, $\mathbf{S_{cb}}$, $\mathbf{S_{cc}}$ respectively.

Comparison of the microwave signal $\mathbf{U_0}$ to the recorded quadrature and in-phase component of the signals $\mathbf{S_{aa}}$ to $\mathbf{S_{cc}}$ within the control unit 42 yields information on their amplitude and phase relative to the signal $\mathbf{U_0}$; amplitude information for the signals $\mathbf{S_{aa}}$ to $\mathbf{S_{cc}}$ is derived within the control unit 42 from the root of the summation of the square of the quadrature and in-phase components of each signal, whereas phase information is obtained from calculating the arctan of the ratio of the quadrature component of each signal to the in-phase component of each signal. The received signals $\mathbf{S_{aa}}$ to $\mathbf{S_{cc}}$ thus define nine equations relating to phase and nine

equations relating to gain in the form of Eq.1 above. The equations are solved within the control unit 42 to yield the relative phase and gain characteristics of the transmitters TXa, TXb, TXc and the receivers RXa, RXb, RXc relative to one another when operated with array elements 30a, 30b and 30c respectively. The phase and gain characteristics are then taken into account within the control unit 42 when controlling the microwave phased-antenna array 26 in order to ensure optimum microwave beam formation and reception.

The number of array elements 30 need not be limited to three as shown in Figure 3. Some phased-antenna arrays 26 may comprise several hundred elements 30 in order to achieve a highly-directional polar response characteristic. Furthermore, if correction of phase and gain errors arising in the array elements 30 and the receivers 34 is required only, it is sufficient to transmit a single microwave pulse signal from one of the phased-antenna array elements 30 in the array 26 in order to obtain a sufficient number of measurements from the array elements operating as receivers for calculating the relative reception gain and reception phase characteristics of the phased-antenna array within the control unit 42.

Referring now to Figure 1, the dipole 2 may be replaced with another form of antenna such as a loop antenna. Moreover, as an alternative to using an optical control signal through the optical fibre 12, control of the reflector 1 may be achieved by it being optically flood-illuminated to which the interface element 6 responds directly. Furthermore, control of the reflector 1 may also be achieved with an electrical conductor conveying an electrical control signal and employing a suitably adapted interface element 6; a disadvantage of employing an electrical conductor instead of an optical fibre is that it may cause spurious reflections of incident microwave radiation which may result in perturbations in the polar response of the radar system during normal operation of the radar system when interrogating a remote scene.

In another embodiment of the reflector 1, the dipole 2 is fabricated from a photo-conductive material such as selenium whose electrical conductivity may be altered between high and low values by varying the intensity of optical illumination incident

upon it. Such a dipole may be used for calibrating a radar system and may be made conductive during a period when the radar system is being calibrated by applying optical flood illumination to it, and effectively non-conducting during a period when the radar system is interrogating a remote scene by removing the illumination which renders the dipole transparent to incident microwave radiation. The dipole may be fabricated from a thin film of photo-conductive material deposited on an insulating substrate and patterned to delineate a dipole structure. The advantage of this is that the switch 4 and the interface element 6 are not required because their function is performed by the dipole itself, which may be connected directly to the terminal I_3 on the acoustic-wave delay line 8.

The reflector 1 may also be used with conventional non-phased-array radar systems employing mechanical beam steering. In this case, the reflector 1 may be used for obtaining a polar response characteristic of the conventional radar by measuring received delay-return signal amplitude for a number of different radar beam steering directions relative to the reflector 1. Moreover, delayed return signals from the reflector 1 may be used for calibrating target-range measurement accuracy of the conventional radar system.

CLAIMS

1. A reflector arranged to receive radiation and to re-radiate a relatively delayed return signal in response thereto.

2. A reflector according to Claim 1 including means for enabling and disabling transmission of the delayed return signal from the reflector.

3. A reflector according to Claim 2 including optical illuminating means for enabling and disabling transmission of the delayed return signal from the reflector.

4. A reflector according to Claim 3 in which the means for enabling and disabling transmission of the delayed return signal includes an optical fibre for conveying an enabling/disabling signal to the reflector.

5. A reflector according to Claim 3 or 4 incorporating a dipole of photoconductive material switchable between non-conducting and conducting states in response to optical illumination from the illuminating means.

6. A reflector according to any preceding claim in which the means for delaying microwave radiation received at the reflector prior to transmission from the reflector incorporates an acoustic-wave delay line.

7. A reflector according to Claim 6 in which the acoustic-wave delay line is fabricated from lithium niobate, lithium titanate or quartz.

8. A reflector according to Claim 6 in which the acoustic-wave delay line incorporates a silicon substrate with a zinc oxide surface film for transduction of microwave radiation to and from the silicon substrate.

9. A reflector according to any preceding claim in which the reflector is partially surrounded by a microwave-absorbing cladding layer.

10. A reflector incorporated in a pulse-echo target location system, the reflector being operative to re-radiate a relatively delayed return signal in response to a signal received at the reflector from the system, and the system including calibrating means for determining system characteristics in response to the reflector return signal.

11. A reflector according to Claim 10 including means for enabling and disabling transmission of the delayed return signal from the reflector.

12. A reflector according to Claim 11 including optical illuminating means for enabling and disabling transmission of the delayed return signal from the reflector.

13. A reflector according to Claim 12 in which the means for enabling and disabling transmission of the delayed return signal includes an optical fibre for conveying an enabling/disabling signal to the reflector.

14. A reflector according to Claim 12 or 13 in which the reflector incorporates a dipole of photoconductive material switchable between non-conducting and conducting states in response to optical illumination from the illuminating means.

15. A reflector according to Claim 10, 11, 12, 13 or 14 in which the means for delaying microwave radiation received at the reflector prior to transmission from the reflector incorporates an acoustic-wave delay line.

16. A reflector according to Claim 15 in which the acoustic-wave delay line is fabricated from lithium niobate, lithium titanate or quartz.

17. A reflector according to Claim 15 in which the acoustic-wave delay line incorporates a silicon substrate with a zinc oxide surface film for transduction of microwave radiation to and from the silicon substrate.

18. A reflector according to Claim 10, 11, 12, 13, 14, 15, 16 or 17 in which the reflector is partially surrounded by a microwave-absorbing cladding layer.

19. A reflector according to Claim 10, 11, 12, 13, 14, 15, 16, 17 or 18 for calibrating phased-array radar systems comprising a phased-antenna array having a plurality of array elements and associated transceivers in which the reflector is operative to re-radiate to the array elements a relatively delayed return signal in response to radiation received at the reflector therefrom, and the calibrating means is operative to obtain the relative phase and gain characteristics of array elements and their associated transceivers from their received signal developed in response to the reflector return signal.

20. A reflector according to Claim 10, 11, 12, 13, 14, 15, 16, 17, or 18 for calibrating phased-array radar systems comprising a phased-antenna array having a plurality of array receiving elements and associated receivers and a transmitting element with associated transmitter, in which the reflector is operative to radiate to the array receiving elements a relatively delayed return signal in response to radiation received at the reflector from the transmitting element, and calibrating means is operative to obtain the relative phase and gain characteristics of array receiving elements and their associated receivers from their received signal developed in response to the reflector return signal.

21. A reflector according to Claim 19 or 20 wherein the reflector is located in front of the phased-antenna array and responds to microwave radiation emitted from the phased-antenna array.

22. A reflector according to Claim 19, 20 or 21 wherein the phased-antenna array is located in a rear region of an aircraft nose-cone and the reflector is located at

an apex region of the aircraft nose-cone, substantially furthest from the rear region of the nose cone.

23. A radar system incorporating a reflector operative to re-radiate a relatively delayed return signal in response to radiation received at the reflector from the radar system, and calibrating means for determining radar system characteristics in response to the reflector return signal.

24. A radar system according to Claim 23 including means for enabling and disabling transmission of the delayed return signal from the reflector.

25. A radar system according to Claim 24 including optical illuminating means for enabling and disabling transmission of the delayed return signal from the reflector.

26. A radar system according to Claim 25 in which the means for enabling and disabling transmission of the delayed return signal includes an optical fibre for conveying an enabling/disabling signal to the reflector.

27. A radar system according to Claim 25 or 26 in which the reflector incorporates a dipole of photoconductive material switchable between non-conducting and conducting states in response to optical illumination from the illuminating means.

28. A radar system according to Claim 23, 24, 25, 26 or 27 in which the means for delaying microwave radiation received at the reflector prior to transmission from the reflector incorporates an acoustic-wave delay line.

29. A radar system according to Claim 28 in which the acoustic-wave delay line is fabricated from lithium niobate, lithium titanate or quartz.

30. A radar system according to Claim 28 in which the acoustic-wave delay line incorporates a silicon substrate with a zinc oxide surface film for transduction of microwave radiation to and from the silicon substrate.

31. A radar system according to Claim 23, 24, 25, 26, 27, 28, 29 or 30 in which the reflector is partially surrounded by a microwave-absorbing cladding layer.

32. A radar system according to Claim 23, 24, 25, 26, 27, 28, 29, 30 or 31 having a plurality of array elements and associated transceivers in which the reflector is operative to re-radiate to the array elements a relatively delayed return signal in response to radiation received at the reflector therefrom, and the calibrating means is operative to obtain the relative phase and gain characteristics of array elements and their associated transceivers from their received signal developed in response to the reflector return signal.

33. A radar system according to Claim 23, 24, 25, 26, 27, 28, 29, 30 or 31 having a plurality of array receiving elements and associated receivers and a transmitting element with associated transmitter, in which the reflector is operative to radiate to the array receiving elements a relatively delayed return signal in response to radiation received at the reflector from the transmitting element, and the calibrating means is operative to obtain the relative phase and gain characteristics of array receiving elements and their associated receivers from their received signal developed in response to the reflector return signal.

34. A radar system according to Claim 32 or 33 wherein the reflector is located to respond to microwave radiation emitted from the phased-antenna array.

35. A radar system according to Claim 32, 33 or 34 wherein the phased-antenna array is located in a rear region of an aircraft nose-cone and the reflector is located in an apex region of the aircraft nose-cone.

36. A method of calibrating reception characteristics of a phased-array radar system incorporating a plurality of array elements and associated transceivers, the method including the steps of :-

(a) arranging for the radar system to incorporate a reflector operative to re-radiate to the array elements a relatively delayed return signal in response to radiation received at the reflector therefrom, and to incorporate calibrating means responsive to the return signal;

(b) selecting an array element to radiate a signal for receipt at the reflector, for delay therein, and then for re-radiation as a delayed signal to the array elements;

(c) receiving the delayed signal at the array elements for generation of respective calibration signals in response thereto;

(d) receiving the delayed calibration signals at the calibrating means for determination of relative reception gain and phase characteristics of each such signal relative to the others;

(e) comparing the determined relative reception characteristics with those required and evaluating deviations therebetween;

(f) employing the deviations to correct the radar system performance.

37. A method of calibrating a radar system according to Claim 36 in which in step (f) deviations are employed to provide correction trims for the transceivers.

38. A method for calibrating a radar system according to Claim 36 in which in step (f) evaluated deviations are subtracted from phase and gain control signals.

39. A method for calibrating transmitting characteristics of a phased-array radar system incorporating a plurality of array elements and associated transceivers, the method including the steps of :-

(a) arranging for the radar system to incorporate a reflector operative to re-radiate to the array elements a relatively delayed return signal in response to radiation received at the reflector therefrom, and also to incorporate calibrating means responsive to the return signal;

(b) selecting a plurality of array elements to radiate sequentially a signal for receipt at the reflector, for delay therein, and then for re-radiation as a sequence of delayed signals to the array elements;

(c) receiving the sequence of delayed signals at a selected array element for generation of a calibration signal in response thereto;

(d) receiving the calibration signal at the calibrating means for determination of relative transmission gain and phase characteristics of the array elements;

(e) comparing the determined relative transmitting characteristics with those required and evaluating deviations therebetween;

(f) employing the deviations to correct the radar system performance.

40. A method of calibrating a radar system according to Claim 39 in which in step (f) evaluated deviations are employed to provide corrections trim for the transceivers.

41. A method of calibrating a radar system according to Claim 39 in which in step (f) evaluated deviations are subtracted from phase and gain control signals.

The Patent Office

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Claims searched: all

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Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O):

Int Cl (Ed.6):

Other: Online:- WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB2134740A	Mark Resources & US4613863 whole document	1,2,6,7,8
X	GB1572148	Westinghouse Electric Corp whole document	1,10,23
X	EP0282195A2	Raytheon Co & US5262787 whole document	1,2,6,7,8, 10,11, 15-17,23, 24,28-30
X	US4679049	US Phillips Corp whole document	1,2,6,7,8, 23,24, 28-30

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